GAT/DeLiTe: An Autonomous System for Complete micro-Gyroscope Characterization

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Abstract—The advancement of the MEMS micro-gyroscope development effort [1][2] at the Jet Propulsion Laboratory has necessitated the production of autonomous test equipment. A cost effective and efficient method of performing qualification testing and lifetime characterization was developed in response. Implemented as a set of two independent programs, the Gyroscope Automated Testbed (GAT) and the Device Lifetime Testbed (DeLiTe), provide short term stability and response characterization and long term stability analysis. The two programs were designed to automate the time consuming task of performance analysis, accommodate the simultaneous testing of multiple devices, and reduce the risk of operator induced errors.

Both systems are implemented on standard Intel-based personal computers using off-the-shelf data acquisition hardware. Specialized hardware or dedicated systems are not required, which results in a low cost system solution. This paper discusses the design and implementation of the two programs.

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1. INTRODUCTION

Cost effective and time efficient autonomous test systems are of increasing importance in the research and development environment. Automated systems allow scientists and engineers to focus on improving their results, instead of obtaining them. Automated systems also provide a method of reporting results in a clear, concise, and consistent manner. The MEMS micro-gyroscope program at NASA's Jet Propulsion Laboratory upholds the mantra of 'Better, Faster, Cheaper' through its implementation of automated test systems for gyroscope characterization. 'Better' by increasing the accuracy of the results, reducing the human error factor involved in the testing process, and providing a consistent manner of result reporting. The capability of the programs to automatically test multiple devices concurrently, eliminates the need for a dedicated test engineer; coupled with the implementation of the systems on standard computer equipment demonstrate 'Faster' and 'Cheaper'. Comprised of two independent programs for qualification and lifetime reliability testing [3], the suite is designed to integrate into the development process to provide feedback on the performance capabilities of the micro-gyroscope.

The qualification program performs a rotational response characterization and a short-term stability analysis. Drift stability, Green chart analysis, power spectral density, n-th order data correction on any acquired data set (i.e. drift stability corrected by temperature), and turn-on stability are currently supported by the program. Multiple signals can be acquired and analyzed from each device; multiple devices can be tested simultaneously. Current hardware allows for analog, digital, IEEE 488, and temperature measurements.

The lifetime system analyzes the long-term stability and failure probability of devices along with correlating signals such as temperature. Hardware and software abstraction allows the analysis of multiple devices (not just gyroscopes) with acquisition of multiple signals from each device.

2. QUALIFICATION TESTING

Motivation

The purpose of the qualification test is to determine the operating characteristics of a device. Operational characteristics can be separated into two categories: 1) rotational response and 2) short-term stability (to include noise analysis and turn-on stability).

System Overview

The Gyroscope Automated Testbed software serves as an interface between the various components of the test system. (See Figure 1). The software was developed using Microsoft Visual Basic on an Intel Pentium II – 400 MHz platform with a 10 Gigabyte hard drive and 192 Megabytes of RAM. The data acquisition hardware consists of a

National Instruments PCI-MIO-16XE-10, 16 bit, multi-function I/O card, a National Instruments PCI-GPIB interface controller, a National Instruments 5B resistive thermal device (RTD) temperature sensor, and a Hewlett Packard 53131A universal counter. A Trio-Tech, S347B single-axis rate table serves as the rotation platform.

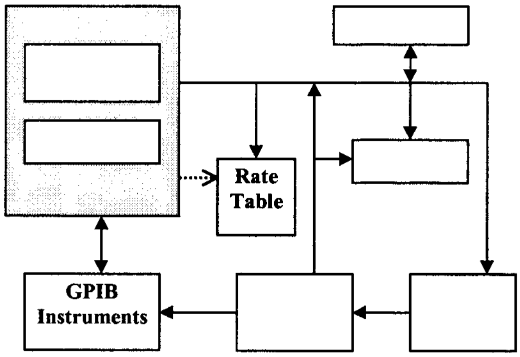

Figure 1 – System Block Diagram

Capabilities

The software was designed to be flexible. Individual tests, customizable test parameters and support for various data acquisition hardware is the result.

In terms of hardware, the system can accommodate an array of inputs; a combination of up to five devices and up to 15 signals can be monitored. Abstraction of the data acquisition hardware interface (through the novel concept of GPIB 'profiles') allows virtually any GPIB instrument to be used for input or output. Support for both analog controlled and GPIB controlled rate tables is provided. Up to two axis rate tables may be controlled through the analog interface; the GPIB interface supports up to three. The GPIB interface also supports the 'Aerosmith Table Language' (ATL) in addition to the standard GPIB command language. Signal generation from the on-board digital-to-analog converters is also allowed, although only pulse train generation is currently supported. (See Future Enhancements).

From the software side, the system currently performs several characteristic determination tests, each of which is described in detail in this paper. These are:

- Rotational Response
- Drift Stability
- Power Spectral Density
- Turn-On Stability

Several supporting tools are also available. A method of correlating any data set by another is handled through the use of data correction, which may be done automatically, or interactively. Temperature can be monitored through the RTD sensor, though specific temperature tests (i.e. drift stability or rotational response as a function of temperature) are not directly supported. Tools for performing an offline drift stability test, on previously acquired data, and for processing data sets, are also available. Test results, including all charts and pertinent data, are compiled into a Microsoft Word document at the completion of all tests.

Data Acquisition Kernel

Data can be acquired either through the analog-to-digital converters of the data acquisition card using the 'analog channel definitions' or through GPIB instruments using 'GPIB profiles'. Accordingly, there are two methods in which the data is acquired from the devices and passed to the various processing and display methods. The analog channel inputs use a double buffered input scheme in which the channels are constantly sampled at their respective rates. The data from all the channels is stored in the first half of on-board buffer as soon as all channels have been sampled. At a sampling rate of 100 Hz, 100 samples, temporally spaced evenly, are acquired from each channel. (There is a small difference in time, 40 µsec maximum with the current configuration, between the points sampled from different channels, see Figure 2). The data acquisition card continues to perform sampling passes of the analog channels, but stores the data in the alternate half of the buffer when sampling is complete. This process occurs independent of the program once it has begun. The program retrieves data from the buffer every second and processes it. The retrieval is triggered by a timer with error of less than 5 milliseconds. Buffer overflow (or underflow) errors are extremely rare with this configuration and occur only when attempting to multitask CPU-intensive programs.

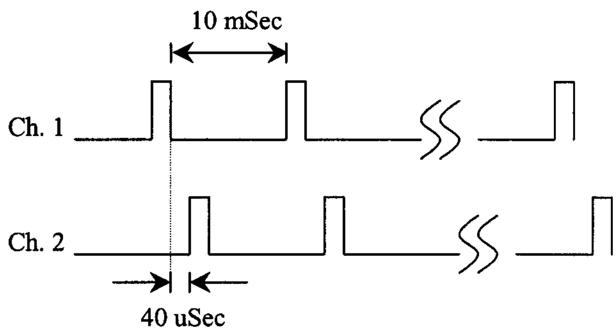

Figure 2 –Timing Diagram for 100Hz Sample Rate

The GPIB acquisition process is considerably simpler. Each GPIB profile specifies a 'data poll time', which is given in whole seconds. The same timer used in the analog channel acquisition is used to trigger the data sampling of the GPIB instruments. The 'action string' specified in the profile is sent to the device at each trigger; the data stream is immediately retrieved from the device and processed by the program.

Analog Input Channel Definitions

Analog input channels are separated into four categories: inactive, data, user and predefined. Each of the analog input channels (16 with current hardware configuration) can be mapped to one category, and hence one function in the program. The data channels are reserved for signal inputs directly from the devices under test. These data signals are used for all tests. User defined channels are for signals to be monitored or used in the data correction routines, but are not analyzed for rotational response, drift stability (Green chart), PSD, or turn-on stability. Data acquired with a user defined channel data is displayed only during the drift stability test. The predefined channels are reserved for analog frequency and analog temperature inputs ONLY; they are monitored during the drift stability test. Inactive channels are ignored for all tests.

The input channels can be individually configured for different gains, bias (which can be zeroed before beginning the tests), display chart units and the display chart Y-axis label. Data channels may be configured such that the bias is removed (bias is sampled at the start of the test). Data may be logged for user defined and predefined channels and a correlated source (a data channel) may be specified: in this case, the user defined channel output and data is displayed and saved with the correlated source. (See Appendix B.1).

GPIB Profiles

The concept of a profile to interface with a GPIB instrument provides a method of interacting with virtually any GPIB compliant instrument. The profile contains information used to communication with the instrument. This includes the address and identity, command strings for initialization, task action, and device close/reset, data acquisition time, interpretation for device data format, and destination of the data (chart, file, or both). (See Appendix B.2).

Profiles can be activated and deactivated for any given test depending on what signals are desired. Multiple profiles can be created for each instrument; any number of which may be active, provided the device supports it and the profiles do not conflict. Profiles may be used to acquire data from a device, or to control a GPIB compliant device. Any number of profiles may be created, but a limit of 10 active profiles is imposed in the software to prevent a computational overload. The profile allows the software access to the multitude of GPIB instruments currently on the market, ensures compatibility with future hardware, and provides an alternative to using analog-to-digital converters on the data acquisition board.

Rotational Response

The rotational response test characterizes the linear response of the device under rotational stimulation. Two sub-tests are performed under the rotational response test: The first measures the response of the device, the second measures the bias. The device is rotated from the most negative range (clockwise about the input axis) to the most positive range (counterclockwise about the input axis), during which time rotation response is measured at every increment. After every increment of rotation, the device is brought to rest and the bias is measured. The process of rotating the device through the specified range is done three times, with the second run in the opposite direction (most positive rate to most negative rate).

Configurable test options include:

- Rotation rate range (+/- 1 deg/sec to +/- 100 deg/sec)
- Rotation rate increment (.01 deg/sec to 20 deg/sec)
- Sample time, defined as the time during which data is acquired from the device
- Delay time, defined as the time between the point at which the rotational rate is set and the point at which data acquisition begins
- Total test time may be configured instead of sample and delays times. If used, the sample and delay times are calculated and set as equal as possible.
- Axis of rotation: Only one axis in a multi-axis configuration may be used.
- Data logging

Outputs from this test are:

- Rotational data – Figure 3, Equation 1. Data acquired from the device during periods of rotation in mV. This data is corrected by the average of both the initial bias measurement and the most recent bias measurement.

$$\begin{aligned} &R_i = R_s - (B_0 - B_s)/2 \\ &where: R_s \text{ is rotation data at rate 's'} \\ &B_0 \text{ is initial bias, } B_s \text{ is bias data at rate 's'} \end{aligned} \quad (1)$$

- Zero crossing - The rotation rate, in mV, indicated by the device at an actual rotation rate of 0 deg/sec. Ideally 0, this value indicates the bias of the device for the given run.
- Zeroes – The average of the acquired rotation data, in mV. Ideally 0, this value gives an indication of linearity and bias.
- Responsivity – Equation 2. The scale factor of the device under test in mV/deg/sec.

$$SF = \frac{\sum_{i=1}^{N} R_i}{\sum_{i=1}^{N} s_i} \quad where: N = \frac{range}{increment} + 1 \quad (2)$$

- Residuals – Equation 3. Difference between the actual rotational data and the expected value given the responsivity (in mV).

$$\begin{aligned} &L_s = R_i + SF * s_i - \overline{R} \\ &where: \overline{R} \text{ is the average of rotation data} \end{aligned} \quad (3)$$

- Bias drift – Equation 4. Slope of the linear fit of the zero crossing data in mV/sec. Ideally 0, this value indicates a drift, or change over time, of the bias (zero crossing).

$$D=\frac{4\sum_{i=1}^{N+1} i*\sum_{i=1}^{N+1} Z_i-4\sum_{i=1}^{N+1}(Z_i*i)*(N+2)}{\left(\left(4\sum_{i=1}^{N+1} i\right)^2-\sum_{i=1}^{N+1}(4*i)^2\right)*(N+2)} \tag{4}$$

$where: Z_i$ are the zero crossing data

- Bias offset – Equation 5. Y-intercept of the linear fit of the zero crossing data in mV. Ideally 0, this value indicates the average bias for all three runs.

$$BO=\frac{4\sum_{i=1}^{N+1} i*4\sum_{i=1}^{N+1}(Z_i*i)-\sum_{i=1}^{N+1} Z_i*\sum_{i=1}^{N+1}(4*i)^2}{\left(\left(4\sum_{i=1}^{N+1} i\right)^2-\sum_{i=1}^{N+1}(4*i)^2\right)*(N+1)} \tag{5}$$

- Residual standard deviation - Standard deviation of the residual data. Ideally 0.
- Offset (zero crossing) standard deviation - Standard deviation of the zero crossing data. Ideally 0.
- Non-linearity – Equation 6. Ratio of the difference between the residual and offset standard deviations with the maximum output of the device (in PPM). Ideally 0, this value represents the linearity of the device's response. A device produces a non-linear response if it is tested beyond its maximum rotation rate.

$$\begin{aligned}&NL_i = 2*10^\wedge 6*(\sigma_{ri}-\sigma_{oi})/SF*range\\&where: \sigma_{ri} \text{ is the standard deviation of the}\\&\text{residual data. } \sigma_{oi} \text{ is the standard deviation}\\&\text{of the zero crossing data.}\end{aligned} \tag{6}$$

- Hysteresis – Equation 7. The largest difference between rotational data at equivalent rates taken from opposite runs (i.e., between runs 1 and 2 or between runs 2 and 3). Ideally 0, this value indicates a difference in the device response due to opposite rotations.

$$\begin{aligned}&H=\max(R_{i,r=1}-R_{i,r=2}, R_{i,r=3}-R_{i,r=2})\\&where: r \text{ is the rotation run iteration:}\\&(1,3 \text{ are most negative rate to most positive rate}\\&2 \text{ is most positive rate to most negative rate})\end{aligned} \tag{7}$$

- Composite error – Equation 8. The ratio of the largest residual data value to the test range (in mV/deg/sec). Ideally 0, this value provides a quantitative measure of error.

$$CE=\max(L_i)/range \tag{8}$$

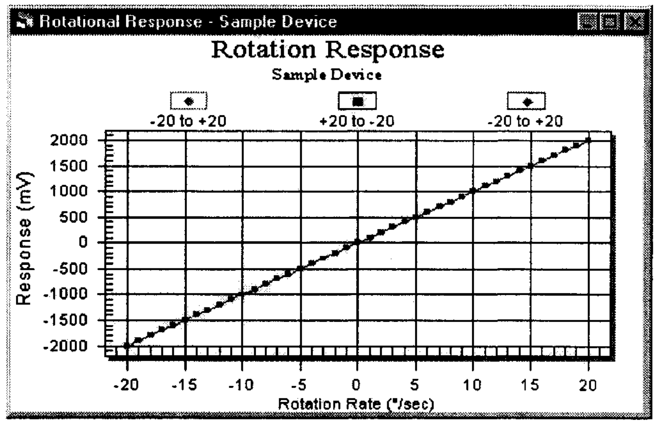

Figure #3 – Rotational Response Test Output Chart

Drift Stability

The drift stability test performs a noise analysis on the devices under test. The purpose behind a noise analysis is to determine the sensitivity of the device. Typically, one hour of data is acquired from a device at rest. The drift, or change in mean value of the data, can be determined by plotting the acquired data versus time. The calculation of the Allen variances of the drift stability data is used to create a Green chart [3]. Drift stability data is converted from its raw voltage to angle value according to Equation 9. The Green chart is derived from the angle data according to Equation 10:

$$\phi(t)=\phi(t-T)+\omega(t)T \tag{9}$$

$$\sigma^2(\tau)=\frac{1}{2N\tau^2}\sum_{k=1}^{N}[\phi(t_k+2\tau)-2\phi(t_k+\tau)+\phi(t_k)]^2 \tag{10}$$

The drift stability test is not limited to the analysis of the device output. The test can also be used to monitor other signals. GPIB 'profiles', user defined analog input channels, and the predefined channels can be configured for use during this test. The signals acquired may be correlated with the drift of the device using the data correction tool, or may simply be monitored.

Configurable test options include:

- Total test time
- Zero or constant rotation rate
- Manner of data correction (none, automatic and interactive)
- Data logging
- Plot resolution (for longer data acquisition periods)

Outputs from the test include:

- Plot of the drift stability test (and corrected drift stability test if applicable)
- Green chart computed on drift stability data (and corrected chart if applicable)
- Minimum and maximum uncertainty, given in degrees per hour
- Angle - the angle through which the device has turned through during the test (as offset from an initial angle of 0; ideally 0).
- Degrees - the number of degrees which the device has drifted during the test (ideally 0).

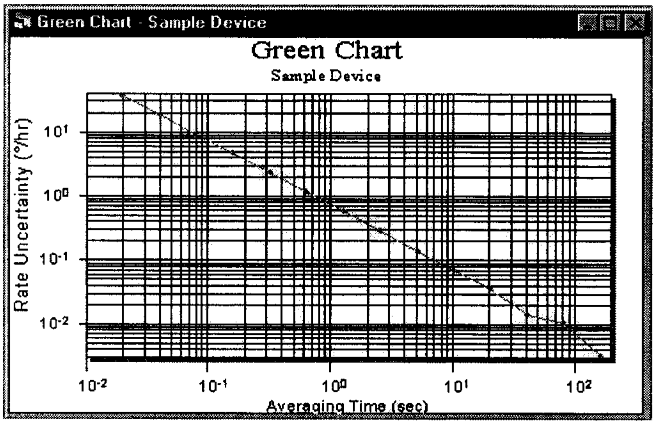

Figure 4 – Sample Green Chart
(Random noise input signal)

Data Correction

The drift in output of a device can be attributed to several factors. The data correction routine provides a method of correlating the drift to another sampled data set. The data correction tool is capable of correcting any sampled data set with a second one, but is primarily designed for the correction of drift data. The input data set may also be corrected by time, effectively removing the linear time rate of change. Plots of the corrected data set, and a corrected Green chart, if the input set is drift data, are created (see Figure 5).

The data correction is done in several steps. A comparison of the length the original data set $<B_i>$ is made to the correction set $<C_i>$. The correction set is interpolated, if needed, to provide an equal number of points as the original set. $<B_i>$ is then scaled and its offset is removed according to Equation 11 to produce $<B_i'>$. A new data set $<D_i>$ is created with data points of pairs (C_i, B_i') and is sorted by ascending values of $<C_i>$. Any degenerates (multiple point pairs with equal ordinates) in $<D_i>$ are removed by averaging the $<B_i'>$ values. A polynomial fit is calculated over $<D_i>$ and the coefficients of the function are used to calculate the corrected values $<B_{ic}>$ according to Equations 12 and 13.

$$B_i' = \frac{(B_i - B_0 - B_{Avg})}{B_{Avg}} \tag{11}$$

$where$: B_0 is the first point in the data set

B_{Avg} is the average of the original data set

$$B_{if}' = \sum_{j=1}^{N} m_j (C_i)^{j-1} \tag{12}$$

$where: m_j$ are the coefficients of the fit function

$$B_{ic} = (B_i' - B_{if}') * B_{Avg} + B_{Avg} \tag{13}$$

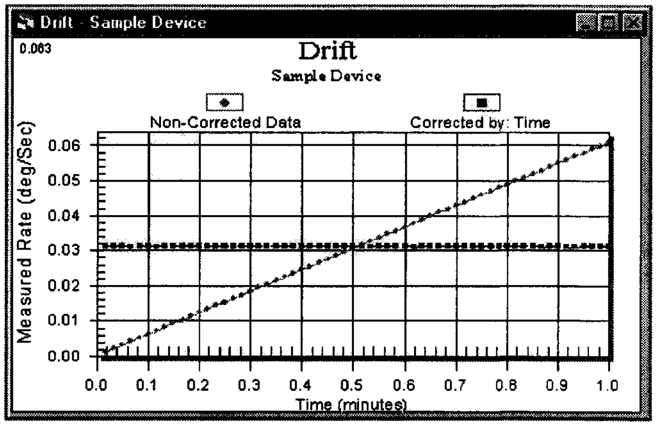

Figure 5 – Drift Stability Data Corrected by Time.

The input data set and correction data set may be any sampled data set, either from a GPIB 'profile' or an analog channel. The correction set can also consist of the time at which the input data set was sampled. Options are provided for the degree of the fit equation, destination of the corrected set (same axes as original data, or a new chart), and whether to plot the fit equation. If data correction is used, the corrected data set is saved in conjunction with the drift stability data in the data output file and are displayed in the report in the drift stability section.

Data correction can be done automatically by specifying the parameters before the drift stability test begins, or may be done interactively once the test is complete. The interactive data correction provides an additional option to specify the coefficients of the fit equation. The coefficients can be determined from the polynomial fit of the data, input manually, or input from a GAT created drift stability file. Previews of the corrected data set, and if applicable, a corrected Green chart are displayed on the screen; the primary output charts are not updated until the operator explicitly chooses to do so. This allows viewing the output of various correction configurations without affecting the original results of the test.

Power Spectral Density

The power spectral density represents the distribution of device output signal over frequency, and gives the relative strength (power) of the signal over the frequency range.

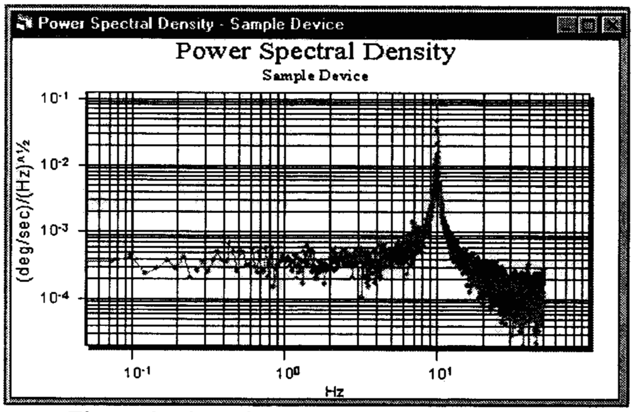

Figure 6 – Sample Power Spectral Density Chart (10 Hz sinusoidal input signal)

The drift stability test is a prerequisite for determining the power spectral density (PSD), as the raw drift data is used in its computation. As a fast Fourier transform (FFT) is used, the input data set is either truncated, or appended with zeroes, to a length that is a power of two. The input set is decimated in time (bit reversal), and a Fourier transform is computed according to Equation 14.

$$
\begin{aligned}
F_k &= \sum_{j=0}^{N-1} e^{2\Pi ijk/N} f_j \\
&= \sum_{j=0}^{N/2-1} e^{2\Pi ikj/(N/2)} f_{2j} + W^k \sum_{j=0}^{N/2-1} e^{2\Pi ikj/(N/2)} f_{2j+1} \qquad (14) \\
&= F_k^e + W^k F_k^o
\end{aligned}
$$

where: F_k^e *is the* k^{th} *component of the even original data set*

F_k^o *is the* k^{th} *component of the odd original data set*

The positive side of the FFT output is normalized according to Equation 15, and plotted as the power spectral density.

$$
\sum_{i=1}^{N} |C_i|^2 \Delta f = \frac{1}{N} \sum_{i=1}^{N} |F_k|^2 \qquad (15)
$$

$$
PSD_i = \sqrt{|C_i|^2}, \textit{for all } i
$$

Configurable test options include:

- Test time (equivalent to drift stability test time)
- Append or truncate input data set to a power of two

Outputs from the test include:

- Power spectral density plot (frequency versus degrees/second/root Hertz)
- Raw data, calculated frequency, power, and the real and imaginary values used in the FFT

Turn-On Stability

The turn-on stability test performs an analysis of the responsivity (scale factor) and bias of the device as a function of power cycles (see Figure 7). The goal of the test is to determine the performance of the device under actual operating conditions where constant power to the device may not be available. The procedure of the test is straightforward: power to the device is turned off for a given period of time between iterations of the rotational response test. The device is allowed to settle after power is restored, prior to the next iteration of the rotation test.

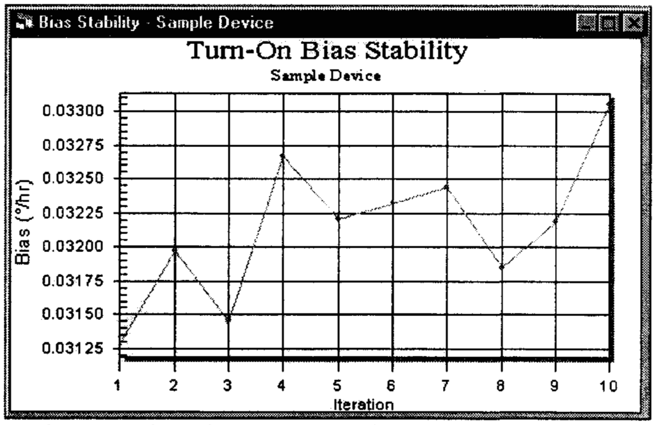

Figure 7 – Sample Turn-On Scale Factor Stability Chart

The same options as the rotational response test are available with the inclusion of the number of iterations of the rotation test and the lengths of time power is on and off.

Outputs:

- Plot of responsivity versus test iteration
- Plot of bias versus test iteration
- Mean and standard deviation of responsivity
- Mean and standard deviation of the bias

Temperature Monitoring

Monitoring the temperature during a drift stability test can provide insight into a possible cause of device drift or unexpected performance. Temperature can be monitored only during the drift stability test using the RTD sensor. The resultant data can be plotted, saved to a file, and/or used in the data correction methods. While direct temperature testing is not currently supported (see Future Enhancements), the GPIB profiles can be used to modify a drift stability test and reconfigure it into a temperature test if a GPIB temperature controller and chamber are available.

Offline Processing Tools

Two tools are available for the offline processing of data files. The first provides functionality identical to the drift stability test described above. Drift stability, Green chart creation, power spectral density and data correction can be done on a previously acquired data set. File types supported by this tool include the GAT standard format and those files in which raw data is stored in column or row format. The type is automatically detected and if more than one row or column of data is present, the user is presented with a choice of which set to analyze. The tool expects the file to contain raw data and must be configured with the parameters in which the data was originally acquired (specifically the sample rate). (See Appendix B.3).

The second tool is for modifying data sets. A data set can be corrupted by a single point, which can differ by several orders of magnitude. The data file processing tool allows selective removal of data from a given file. Data can be removed as a single point, range of points, or a time range of points. The input data set is plotted and a single point or range of points can be removed by graphically selecting the point or start/end points. Alternatively, a time range may be specified in which inclusive data will be removed. (See Appendix B.4).

Report Generation

The automatic report generation feature provides a method of summarizing the results of the tests performed in a clear, concise and consistent manner. The document, created in Microsoft Word, contains all output charts, pertinent data and configuration (for reproducibility). One report is generated for each device tested. (See Appendix A for a section of a sample report).

3. Lifetime Testing

Motivation

The purpose of the lifetime test is to determine the device's reliability over time. Analysis of the test data gives insight into the trends of the output characteristics. Trends can be correlated to other acquired signals (i.e., an increase in the device output due to increasing temperature). Because all data is logged to a file for each device, factors contributing to a decline in performance, or outright failure, can be analyzed.

System Overview

The lifetime test system has been designed, although it is still in the development phase. The base test system is a Pentium II, 400 MHz personal computer containing a National Instruments 16bit AT-MIO-16X data acquisition board, and a National Instruments PCI-GPIB interface controller. The system, running Microsoft Windows NT Workstation 4.0, is connected to each of the devices through a Pickering Interfaces 352 line multiplexer. (See Figure 8). Two 15 Volt, 120 Watt power supplies provide power to the devices under test. Modular mounting boards provide 25 pin connections for signals and power to each device. A single temperature sensor is provided on each board as well. The mounting boards are removable and may be placed in other locations (temperature chambers, vibration chambers, etc.) to accommodate various testing needs. The entire test system (computer, power supply, multiplexer, and mounting boards) is contained in a standard six foot equipment rack.

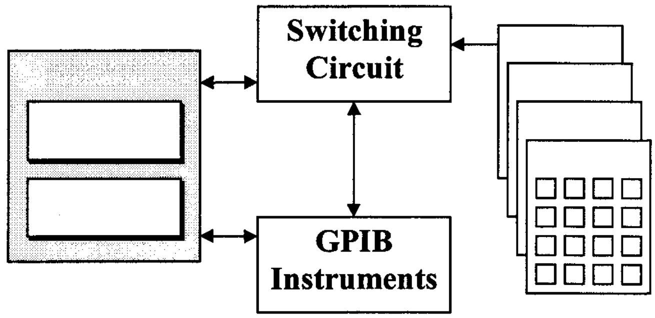

Figure 8 – Lifetime System Block Diagram

Data Acquisition Kernel

The data acquisition kernel used by the program is identical to the one used in the GAT program. In addition, all user interaction functions are suspended during the acquisition period to improve the robustness of the data sampling.

Capabilities

The high capacity of the multiplexer allows up to four signals to be acquired from each device, up to 88 devices. The four modular mounting boards each provide 16 slots; a total of 64 devices can be simultaneously tested. The additional 24 slots supported by the multiplexer are reserved for future expansion. The signals from the devices may be routed to either the data acquisition analog-to-digital converter or to GPIB instruments. Using the same GPIB profile based approach as described in the qualification test, interactivity with a wide range of GPIB instruments is possible.

Current specifications call for the following features:

- 5 year total test time
- Minimum data sampling of one second every hour
- Fault tolerance
- Enabling/Disabling individual devices (hot swappable)
- Automatic faulty device disabling

The data acquired for each device is logged to a file and may be viewed at any time, provided the system is not sampling devices, by selected the desired device and data set. The display chart can be customized to view any given time range of data and can include other signals to determine correlation. Devices may be added or removed from the system at any time, and devices can be disabled automatically if user specified parameters are met. Since all data is logged to a file immediately following its acquisition, fault tolerance is easily implemented. The program provides an option to resume an interrupted test, which will append all new data to specified data sets.

4. Future Enhancements

As with any software, the qualification and lifetime programs are works in progress and are (and will continue to be) frequently updated to meet the needs of its users. The following ideas are being considered for inclusion in new versions of the testing software:

Qualification Test

- The parameters of the Green chart (quantization, white noise, angle random walk, rate random walk and ramp) are not calculated. These can be inferred from the chart, but are not explicitly determined by the program itself.
- Built-in temperature tests (not modified drift stability), including analysis of rotational response versus temperature.
- A test to determine the maximum rate a device is capable of sensing (the minimum rate is determined by the Green chart).
- The capability to monitor GPIB profiles and user defined analog input channels during all tests.
- Autocorrelation of the drift stability data to remove input signal noise.

Lifetime Test

- There currently is no option to create a Green chart from within the lifetime system. Importing the data into the Gyroscope Automated Testbed program can create a Green chart; however, a better solution would be to include the Allen variance analysis in the lifetime system.
- The lifetime system monitors individual devices and does not perform an analysis of the devices as a group. Adding routines to monitor the performance of a group of devices will allow the determination of population parameters, such as the Mean Time Between Failure (MTBF) rating.
- Trend analysis and correlation between various signals is 'left as an exercise' for the operator. Using curve parameterization routines, this analysis could be done automatically.

5. Conclusion

The Gyroscope Automated Testbed has been in active use for the testing of development gyroscopes since July of 1998. It has undergone consistent modifications as new features and improvements are added. As with any software project, the GAT will continue to evolve, providing improved solutions to the testing process. As the GAT system is limited by the amount of memory and processing power available on the computer on which it is run, improvements in computing hardware will also be beneficial. Faster processors and additional memory allow for more devices to be tested simultaneously for longer periods of time.

The Device Lifetime Testbed is still in the development phase and is expected to be online by the start of the millenium.

The future is automation. Autonomous systems shift the focus from the repetitive to the cutting edge. By providing alternative means of accomplishing required tasks in shorter amount of time and with fewer errors, cycle time is reduced, productivity is increased and the bottom line gets brighter.

The two systems presented in this paper accomplish all of the above. With the use of commercially available desktop computers and data acquisition hardware, both systems are viable for both the researcher and producer. Costing less than $10,000 (hardware only, does not include the rate table), the Gyroscope Automated Testbed and the Device Lifetime Testbed provide an autonomous, robust, inexpensive, and flexible system for the analysis of gyroscopes.

References

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[3] Anthony Lawrence, *Modern Inertial Navigation*, New York: Springer-Verlag, 1993.

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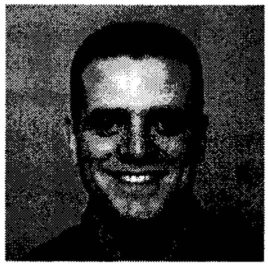
ACKNOWLEDGEMENTS

The authors gratefully acknowledge the suggestions for improvement of the GAT systems from its users. Thanks also go to Dorian Challoner and Dr. Tony Tang for implementation suggestions for the GAT and DeLiTe systems. The research described in this paper was performed by the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration, Office of Space Science.

BIOGRAPHIES



Christopher Evans is an information services and computer sciences associate at the Jet Propulsion Laboratory and a 2LT in the United States Air Force. He is currently working in the MEMS technology group at JPL, where he has worked since 1994 designing and implementing automated test systems and data analysis software. He wrote the software and co-designed the automated test system for the Mars Pathfinder solar arrays in 1995. He has a B.S. in Electrical Engineering from the Illinois Institute of Technology and is currently pursuing a M.S. in Computer Science – Robotics and Automation at the University of Southern California.

Roman Gutierrez

APPENDICES

Appendix A – Sample Report

ROTATION Test Results

Three rotation tests are run. The results from the rotation tests are shown in Figure 1. The difference between this data and a linear least square fit of the data is shown in Figure 2. A detailed description of the data is given below.

Pressure inside the vacuum-sealed package: Not Calibrated
Axis of Rotation: 1

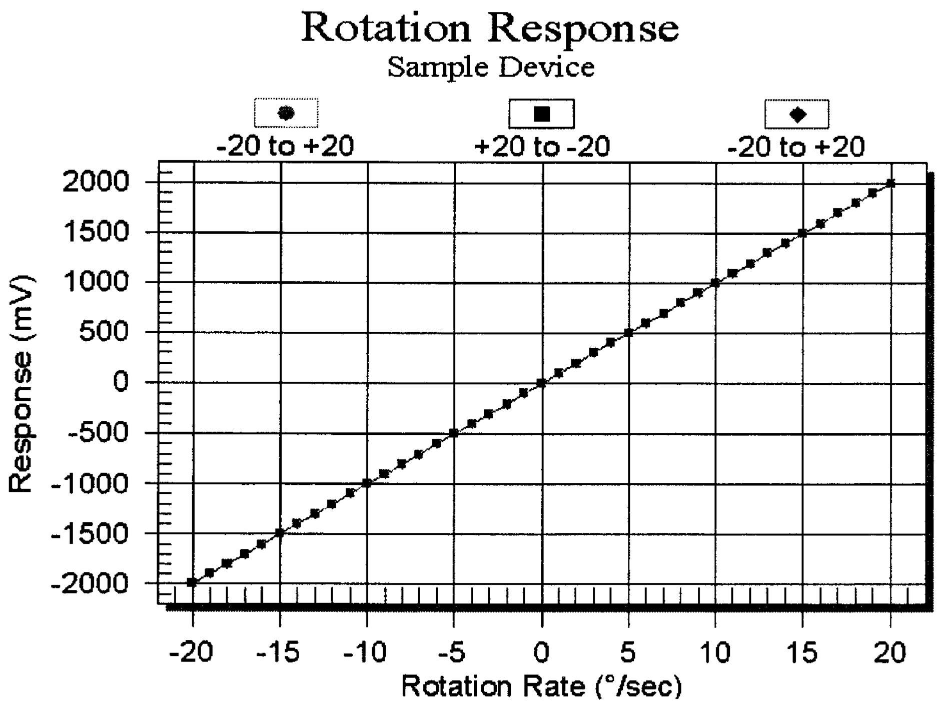
A. First Rotation Test. Gyro is rotated starting at -20 deg/sec and increasing rotation rate in 1 deg/sec increments up to a maximum of +20 deg/sec
1. Responsivity = 1.E+2 mV/deg/sec
2. Zero Crossing = 6.913E-3 mV
3. Bias Drift = -8.599E-5 mV/Sec
4. Average Bias Offset = -2.264E-2 mV
5. Residual Standard Deviation = 1.301E-1 mV
6. Non-Linearity = 4.005E+1 mV
7. Offset Standard Deviation = 4.999E-2 mV
8. Composite Error = -8.296E-3 mV/deg

B. Second Rotation Test. Gyro is rotation starting at +20 deg/sec and decreasing rotation rate in 1 deg/sec decrements to a minimum of -20 deg/sec. This test checks for hysteresis.
1. Responsivity = 1.E+2 mV/deg/sec
2. Zero Crossing = 2.365E-2 mV
3. Bias Drift = -8.321E-5 mV/Sec
4. Average Bias Offset = -3.345E-2 mV
5. Residual Standard Deviation = 1.206E-1 mV
6. Non-Linearity = 4.58E+1 mV
7. Offset Standard Deviation = 2.902E-2 mV
8. Composite Error = -6.832E-3 mV/deg

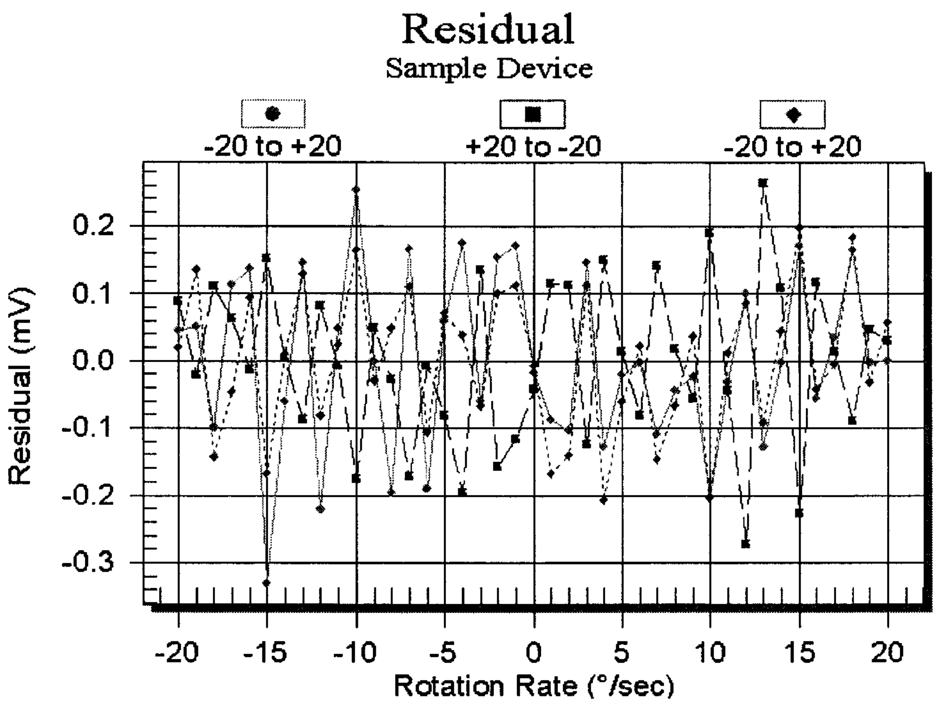
C. Third Rotation Test. Gyro is rotated starting at -20 deg/sec and increasing rotation rate in 1 deg/sec increments up to a maximum of +20 deg/sec. This test checks for repeatability and drift.
1. Responsivity = 1.E+2 mV/deg/sec
2. Zero Crossing = 4.874E-2 mV
3. Bias Drift = 1.125E-4 mV/Sec
4. Average Bias Offset = -6.317E-2 mV
5. Residual Standard Deviation = 1.065E-1 mV
6. Non-Linearity = 3.544E+1 mV
7. Offset Standard Deviation = 3.562E-2 mV
8. Composite Error = -5.159E-3 mV/deg

9. Hysteresis = -2.355E-1 mV

Appendix A – Sample Report Figures 1 and 2



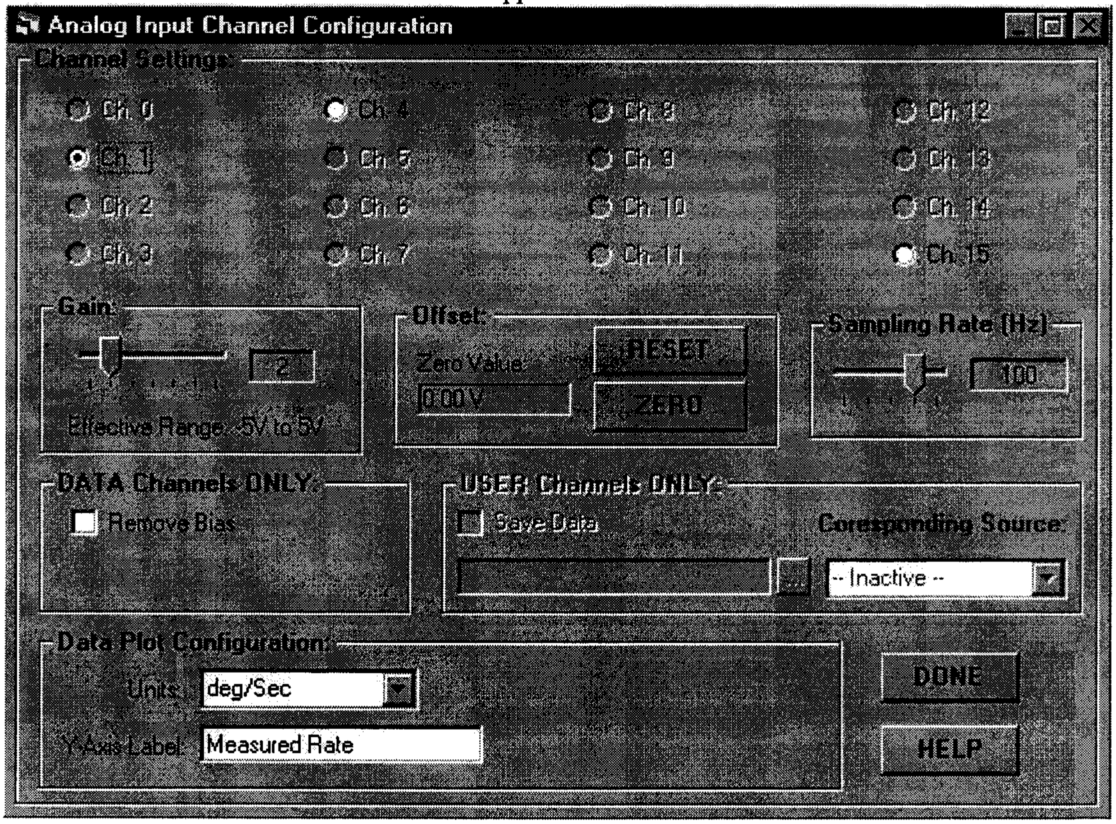
Responsivity = 99.99776 mv/deg/sec



Responsivity = 99.99776 mv/deg/sec

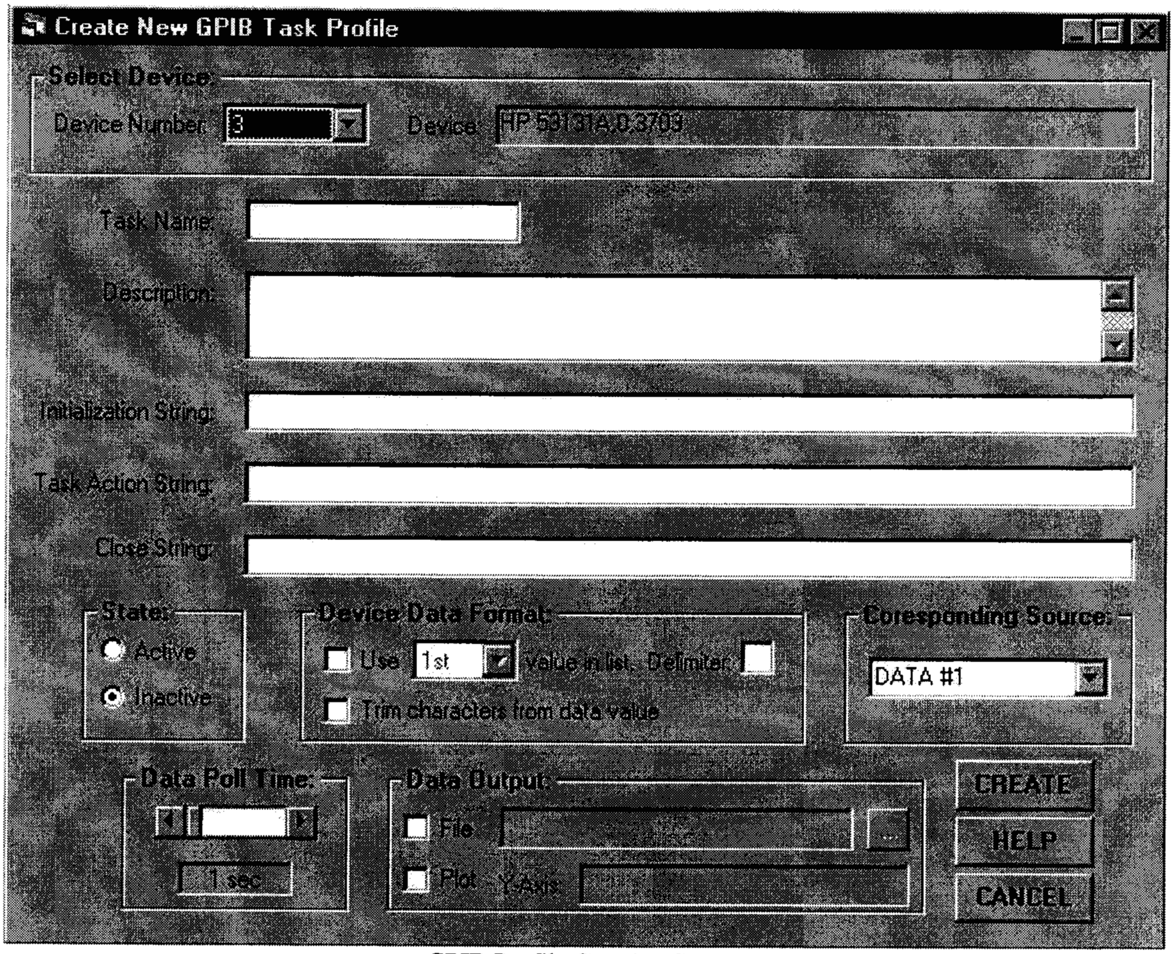
Appendix B – GAT program screen shots

Appendix B.1



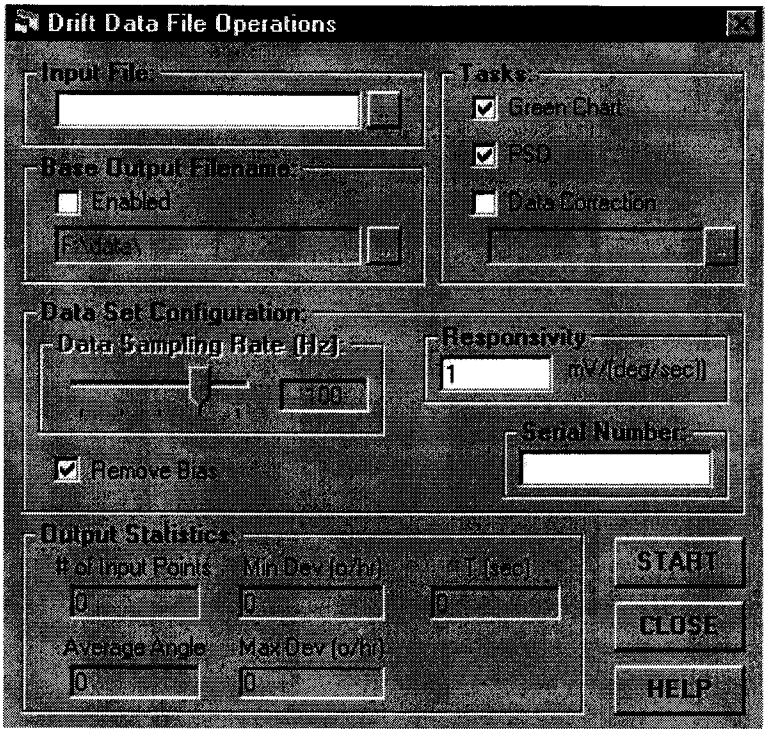
Analog Channel Configuration Screen

Appendix B.2



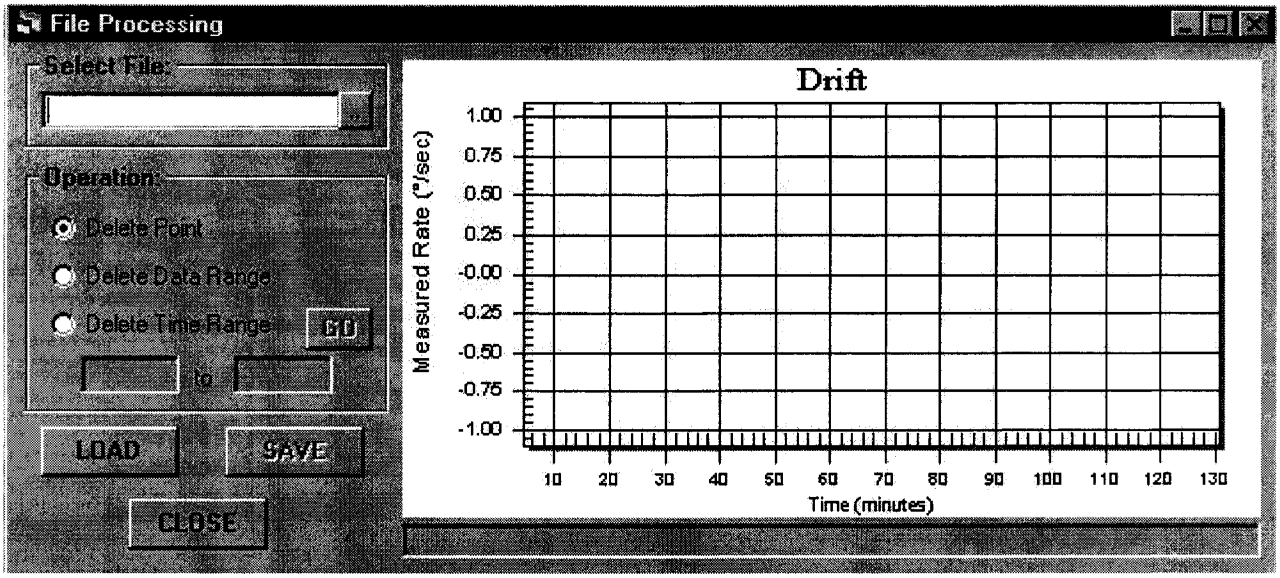
GPIB Profile Creation Screen

Appendix B.3



Offline Drift Stability Tool

Appendix B.4



File Processing Tool